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A Report Upon

THE FLOW OF WATER THROUGH RECTANGULAR NOTCHES

By

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Experiments made at the University of Iowa Hydraulic Laboratory for use in connection with the studies on soil erosion from agricultural lands

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Introduction

This report presents the results of a series of experiments on the flow of water through rectangular notches in metal plates which were conducted for the purpose of calibrating such devices for use in connection with the measurement of the amount of run-off from agricultural lands and the amount of silt washed from the surface of the ground. The experiments were conducted by the Bureau of Agricultural Engineering, U. S. Department of Agriculture, and the State University of Iowa at the University hydraulic laboratory during August and September, 1931.

The report describes the construction of the apparatus, the method of making the tests and presents the experimental results.

PURPOSE OF THE TESTS

In connection with the soil erosion investigations now being conducted by the U. S. Department of Agriculture, measurements are being made on the run-off from and the erosion on very small plots of ground, namely, one tenth and one one-hundredth of an acre. It is impractical to collect the entire amounts of runoff and eroded material from such tracts, hence a representative sample of the runoff and the eroded material must be obtained for each storm.

The soil erosion plots, located on sloping ground, are usually rectangular in shape, from 6 to 10 feet in width and 100 feet or more in length. Metal plates, 12 inches wide, are embedded on edge in the soil along the boundary of each plot so that the surface water must flow over the soil to the lower end of the tract. At this point the water passes into a metal box, in one end of which are located two rectangular notches of different widths, namely 1/2 inch and 3 inches. The discharge through the 1/2 inch notch is collected in a tank while the discharge from the 3 inch notch is permitted to escape. Thus a sample of the runoff and the eroded material is obtained for every storm. For the larger tracts a rectangular notch, 6 inches in width is used in place of the 3 inch notch.

The purpose of the tests was the calibration of the notches so that the total runoff from the tract could be computed after the amount of the sample flow from the 1/2 inch notch was determined. In other words, it was necessary to determine the ratio of flow between the 1/2 inch and 3 inch notches. A constant ratio of flow was highly desirable.

DESCRIPTION OF EXPERIMENTAL APPARATUS

The University of Iowa possesses in its hydraulic laboratory a steel orifice and weir tank, 4 feet wide by 10 feet long by 4 feet 8 inches deep. This tank furnishes the most economical means for calibrating the proposed notches. A plate in which the desired rectangular notches were cut was bolted to one end of the steel tank. The apparatus, as set up for testing, is shown in Plate A. This view shows the 1/2 inch and 3 inch rectangular notches. The plates having the 1/2 inch and 6 inch notches were similar to the other plates, the metal strip separating the smaller and the larger notch being two inches wide for all cases.

The depth of flow through the rectangular notches was measured by means of a hook gage. This gage was set in a stilling well attached to the side of the tank, see Plate B. A pipe connected the stilling well with the tank. The water from the large notch was measured in the laboratory weighing tanks while the water from the 1/2 inch notch was measured in a volumetric tank, 2 ft. 4 inches wide by 8 feet long by 2 feet deep. This tank had a capacity of 30 cubic feet and was equipped with staff gages for reading the depth of the water.

The plates experimented upon consisted of two kinds, galvanized iron, 0.078 inch thick (No. 14 gage), and brass, 3/16 inch thick. Three plates were made of galvanized-iron, one with 1/2 inch and 6 inch notches, two with 1/2 inch and 3 inch notches. The duplicate plate was made for the purpose of determining the effect of any small differences in construction upon the discharge. The lips of the notches were made square, the width of the lips being the thickness of the metal, namely 0.078 inch.

Two plates were made of brass, one with 1/2 inch and 3 inch notches, and one with 1/2 inch and 6 inch notches. The lips of the notches in the brass plates were made 1/32 inch wide.

An adjustable false floor was used in the orifice tank to measure the effect of bottom contraction on the discharge through the notches. Through adjustable vertical walls the effect of side contraction upon the discharge was measured.

The channel used for the regular tests was 4.03 feet wide by 3.5 feet long by 4.5 feet deep.

METHOD OF CONDUCTING TESTS

In order to simulate field conditions it was necessary to measure the discharges through the 1/2 inch and the 3 inch rectangular notches simultaneously as well as separately. The tank used for collecting the water from the 1/2 inch notch was carefully calibrated by weighing the amounts of water required to change the water level in the tank. The large laboratory weighing tank was used to measure the water from the 3-inch notch. The discharges from both notches were timed with stop watches to tenth seconds. The heads on the notches were measured by means of hook gage reading to 0.001 ft. Readings of the hook gage were recorded every 30 seconds during an experiment and the average of these used as the correct head on the notches. A test was made to determine the error caused by such a procedure. The discharge was measured under a fluctuating head. The hook gage readings were then averaged. Another test was then run at a steady head equal to the average head in the previous test. The discharge through the 3-inch notch was the same in each

case. The discharge through the 1/2-inch notch varied only 1 per cent.

Water entered the approach channel over a weir 3 feet in front of the notch plate. No attempt was made to smooth out the turbulence in the water by means of baffles since it was not expected to use baffles in field installations. For heads above 0.93 feet the weir became submerged and a series of standing waves was formed in the channel which may have affected the hook gage readings a little.

All notches were tested at intervals of head of 0.01 foot for heads up to 0.10 feet; 0.05 foot for heads from 0.10 to 0.30 foot; and 0.10 foot for all heads over 0.30 ft. The maximum head run was 1.10 foot and the maximum discharge through two notches, 1.8 c.f.s.

Over 350 tests were made on the following sixteen different set-ups:

Width of Notches, Inches	Kind of Metal Plate	Width of Approach Channel. Feet	Distance Floor below crests of Notches
1/2, 3	Galv. Iron	4.03	3.5 feet
1/2, 3	(first plate)	4.03	6 inches
1/2, 3	" "	4.03	1 inch
1/2, 3	" "	4.03	Level with crest
1/2, 3	" "	2.23	Level with crest
1/2, 3	" "	0.83	Level with crest
1/2, 3	Galv. Iron (duplicate plate)	4.03	1 inch
1/2, 3	"	4.03	Level with crest
1/2, 3	"	4.03	1 inch
1/2, 3	"	4.03	2 feet
1/2, 6	Galv. Iron	4.03	1 inch
1/2, 6	" "	4.03	Level with crest
1/2, 3	Brass	4.03	1 inch
1/2, 3	Brass	4.03	Level with crest
1/2, 6	Brass	4.03	1 inch
1/2, 6	Brass	4.03	Level with crest

For low heads the duration of an experiment was usually 12 minutes. As the head increased this time was gradually diminished to 3 minutes. Sufficient water was run in each test to make the possible error in weighing and measuring negligible.

Effect of Metal Strip Between Notches on Discharge

The space between the notches was 2 inches which was too small a distance to allow the notches to act independently of each other. The effect was to turn the jet from the 1/2-inch notch toward the larger notch. This caused the 1/2-inch jet to cling to the side of the notch as it passed through the opening while the jet sprang free from the opposite side of the notch. The large notch was not affected so noticably by the small notch. The jet came out at right angles to the metal plate although the contraction on the side next to the 1/2 inch notch was not as great as it was on the side opposite.

Effect of Plate Material on Discharge

The reliability of galvanized-iron as a material for notch plates was determined from this investigation. Since such plates cost about one sixth of the price of brass plates, this question was important. The discharges from the three galvanized-iron plates were compared with that from the two brass plates in order to determine the differences if any existed. The brass notches were machined true and were accurately dimensioned. They were regarded as standard and as nearly perfect as would be secured. One of the galvanized-iron plates was somewhat warped but the other two were quite perfect.

The results obtained show that there is little difference between the discharges through the 3-inch or 6-inch galvanized or brass rectangular notches. The variation is small being not more than 1 or 2 per cent throughout practically the entire range of head. This amount of error can easily exist between two tests under identical conditions and can be attributed to the inability to measure all quantities to more than three figures and to the element of judgment which enters into the

drawing-up of the discharge curves. Hydraulic experiments of this type generally check no closer than 1 per cent. Hence it is reasonable to say that the discharge through the large notches was the same whether brass or galvanized-iron plates were used, even though the galvanized-iron notches were not exactly true.

On the other hand the 1/2 inch notches show greater discharge in the galvanized-iron plates than in the brass plates. It is believed that this is due to the fact that the galvanized-iron was thicker than the brass at the edge of the opening, the galvanized-iron plate being 0.078 inch thick and the lip of the brass notch in the brass plate 0.040 inch thick. Since the jet came through the 1/2 inch notch at a considerable angle, the thicker metal caused the jet to cling to it more than to the thinner brass lip and so increased the effective area of discharge. This effect while not large was evident throughout the tests. If this conclusion is correct, it is important that all notches have the same thickness at the edge in order to give uniform performance.

Effect of Depth of Channel of Approach on Discharge

Inasmuch as the depth of the channel of approach to the notches can not be made very great in field installations, the effect of the depth of the approach-channel on the discharge through the notches was investigated quite fully. Tests were run on the same notches with the floor of the approach channel 3.5 ft., 2.0 ft 6 inches, and 1 inch below the crests of the notches and also with the floor level with the crest. There was always a certain amount of turbulence at the entrance to the approach channel and this acted in different ways as the location of the floor was changed. It is believed that the standing waves set up in the

channel of approach caused the readings of head to be slightly different under each position of the floor and that the variation between the discharges at various floor levels is more a measure of the effect upon the hook gage piezometer of the currents in the channel than of actual change of discharge. It is believed that this condition affected the results of the tests with the floor 6 inches below the crest so that this set of tests varies a little from the others. Apparently the velocity of approach is so small that the jet gets its full vertical contraction even with the floor 1 inch below the crest. In all of the tests with the channel of approach 4 feet in width, the velocity of approach was negligible. It would be expected then that this width of channel could have any floor level greater than 1 inch from the crest and still deliver the same amount of water through the notches.

The effect upon discharge of the floor of the approach channel set level with the crest of the notches was investigated since this condition might be used in the field. This set-up gives less discharge for the low heads and greater discharge for the high heads than was obtained for the tests with the floor set below the level of the crest. This was to be expected. As the water approached the notches the velocity was decreased at the bottom due to the friction of the floor and no vertical contraction existed at the low heads. Hence at low heads the effect of the floor level with the crest was to slow up the water and decrease the discharge. For higher heads, however, the effect of floor friction became negligible and the absence of vertical contraction of the under side of the jet caused the jet to have greater cross-sectional area and accordingly greater discharge.

This increase in discharge grew less as the head increased since the area affected became a smaller and smaller portion of the total cross-sectional area of flow.

In the laboratory experiments, the heads on the slots were measured by a piezometer in the side of the approach channel 2 ft. 8 inches in front of the notches for the standard tests. For those tests having different channel conditions the head was measured by a piezometer in the floor near the center of the channel and 12 inches in front of the notches. This variation in location is undoubtedly more extreme than the variations of piezometer locations in field set-ups would be, but the difference in discharge through a notch under otherwise identical conditions is only 2 per cent. Hence, it is felt that the point at which the head on the notches is measured is not of great importance although it is recommended that, if practical in field locations, the piezometer opening may well be placed on the side of the approach channel 2 ft. 8 inches in front of the notches.

The percentage-variation curves generally show a large fluctuation at low heads. It is felt that this is not an indication of widely varying results for the reason that it is impossible to read accurate values from the curves near the origin. Thus one curve for the 1/2 inch notch may show a discharge of 0.0004 c.f.s. at 0.02 ft. head and another 0.0005 c.f.s. The percentage variation of the second from the first is 25 per cent but actually it makes little difference since either quantity is too small to have much effect on the general result.

Effect of Width of Channel of Approach on Discharge.

Tests were made on the following widths of channel of approach: 4.03 ft., 2.23 ft., and 0.83 ft. It was found that, for the same head, reducing the width of the channel of approach increased the discharge through the notches. This is natural since the velocity head of the moving water becomes greater with the narrow channels. However, it is not believed than channels more than 4 feet in width will discharge less water than did the 4 ft. channel, for the velocity of the water is so small that the maximum velocity head is only about 0.001 ft. for that width. Wider channels would reduce this head still further and its effect would be too small to measure. In the 0.83 ft. channel, however, the maximum velocity head was 0.027 ft., an appreciable amount which has considerable effect on the discharge.

Hydraulic Formulas for Rectangular Notches.

In a search through hydraulic literature it was found that H. W. Maynard and J. P. Hurley made a series of experiments in 1907 on the flow of water through narrow rectangular notches at the hydraulic laboratory of Cornell University. See "The Cornell Civil Engineer" April, 1912, pages 384-391. These experiments covered 12 weirs with crests ranging from 3 inches to 51 inches long. The formulas derived by Maynard and Hurley are as follows:

For high heads

$$Q = 2/3 \times 0.571\ l\ h^{1.045} \sqrt{2\ g\ h} \qquad (1)$$

For low heads

$$Q = 2/3 \times 0.553\ l\ h^{0.963} \sqrt{2\ g\ h} \qquad (2)$$

They stated that the "point of change from one law (formula) to another" was not fully apparent.

Naturally formulas 1 and 2 are not strictly applicable to these experiments since these tests have two notches in the side of a metal box separated by a strip of metal only 2 inches wide.

Studies were made of the experimental data by plotting on logarithmic paper the recommended discharges for various heads as given under the chapter "Recommendations." It was found that, with the exception of certain discharges for some of the lowest heads, the data followed the straight line law. The greatest variation was in the data for the 1/2 inch notch for heads under 0.06 ft. The following formulas were derived for the various notches:

For the 1/2 inch notch when used with either the 3-inch or 6-inch notch

$$Q = 3.46\ l\ h^{1.45} \qquad (3)$$

For the 3-inch notch

$$Q = 3.24\ l\ h^{1.50} \qquad (4)$$

For the 6-inch notch

$$Q = 3.14\ l\ h.^{1.47} \qquad (5)$$

Formulas 3, 4, and 5 can be used only with weir boxes, 4 feet wide and 3 feet long with the floor of the box at least 1 inch below the crest of the notches. Naturally a strip of metal 2 inches wide must separate the notches. While formula 3 is a general formula for the 1/2 inch notch, separate formulas for this slot may be derived for use with either the 3-inch or 6-inch notches.

RECOMMENDATIONS

1. Due to the great difference in cost between brass plates and galvanized-iron plates it is recommended that the notches be made in galvanized-iron sheets of No. 14 gage. This gage metal was used in the laboratory tests and should be used in all field installations.

2. It is recommended that all field boxes be made at least 4 feet wide and 3 feet long. Greater widths and lengths than those will not affect the discharge table recommended for use.

3. If the floor of a 4ft. by 3 ft. box is placed 1 inch (or more) below the crests of the notches, the following discharge table may be used for field work, the error in the laboratory tests for any particular notch being in general less than 2 per cent.

	For 1/2-inch & 3-inch Notches			For 1/2-inch & 6-inch Notches		
Head on Notch Feet.	Discharge through 3-inch Notch C.F.S.	Discharge through 1/2-inch Notch C.F.S.	Ratio flow	Discharge through 6-inch Notch C.F.S.	Discharge through 1/2-inch Notch C.F.S.	Ratio flow
0.02	0.0037	0.0006	5.65	0.0055	0.0004	11.68
.04	.0085	.0015	5.50	.0144	.0012	11.41
.06	.0139	.0026	5.38	.0254	.0023	11.24
.08	.0201	.0038	5.28	.0388	.0034	11.10
.10	.0272	.0052	5.25	.0538	.0049	11.02
.15	.048	.0092	5.23	.0985	.0090	10.88
.20	.073	.0139	5.22	.148	.0138	10.80
.25	.102	.0194	5.26	.206	.0191	10.78
.30	.134	.0253	5.30	.268	.0248	10.79
.40	.206	.038	5.43	.412	.038	10.92
.50	.288	.052	5.53	.570	.052	11.00
.60	.375	.067	5.58	.738	.067	11.06
.70	.469	.084	5.61	.924	.083	11.12
.80	.574	.102	5.64	1.122	.100	11.24
.90	.692	.122	5.68	1.350	.119	11.38
1.00	.813	.143	5.74	1.622	.140	11.60
1.10	.964	.166	5.81			

4. If the exact head on the slots is not known, then the following ratios may be used:

	Heads from zero to 0.4 ft.	Heads from 0.4 ft. to 0.8 ft.	Heads from 0.8 ft. to 1.1 ft.
For 1/2 inch and 3-inch notches			
Ratio Q_3 to $Q_{1/2}$ notch	5.3	5.5	5.7
Ratio Q_{total} to $Q_{1/2}$	6.3	6.5	6.7
For 1/2 inch and 6-inch notches			
Ratio Q_6 to $Q_{1/2}$	10.9	11.1	11.5
Ratio Q_{total} to $Q_{1/2}$	11.9	12.1	12.5

The results obtained by the use of this table will not be more than 3 per cent in error except at heads under 0.04 ft. where the discharge is very small.